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APR 80 G K OTTINGER, P E NACHTIGALL, J E HAUN
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Technical Report 537

WIDEBAND UNDERWATER ACOUSTIC FACILITY

GK Ottinger
PE Nachtigall
JE Haun
GE Lingle

April 1980

Final Report: October 1978 - February 1979

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SL GUILLE, CAPT, USN
Commander

HL BLOOD
Technical Director

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A wideband underwater acoustic facility was developed to project and analyze underwater sounds from 44 Hz to 160 kHz. The unique sound projecting system for this facility is composed of a multi-transducer array with individual amplifiers and equalizers to reproduce a relatively flat 165 dB re 1 μPa broadband acoustic signal with a linearity of ± 8 dB. The analyzing system utilizes a broadband omnidirectional hydrophone, a frequency analyzer with a translator, and a tape recorder to analyze the signals from the sound projecting system.

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OBJECTIVE

The objective of this project was to design and build a wideband underwater acoustic generating system with associated test equipment and to measure the parameters of the signals produced. The system was constructed, tested, and evaluated under operational conditions.

RESULTS

1. An acoustic system with a unique filter equalization circuit was designed by project personnel specifically for the multi-transducer array and was the key to generating a relatively undistorted underwater signal.

2. The dynamic capabilities of this sound system, as measured by broadband analyzing and recording equipment, ranged from 44 Hz to 160 kHz with a maximum output level of 165 dB re 1 μPa @ 1 m and a linearity of ± 8 dB.

RECOMMENDATIONS

Since it has been demonstrated that a relatively undistorted wideband underwater sound can be produced, current technology in transducer and integrated circuit design should be applied in an effort to reduce the power requirements and consolidate the instrumentation used in the system.

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CONTENTS

INTRODUCTION

The wideband acoustic facility provides a unique capability to project, monitor, record and analyze wideband underwater acoustic signals with a maximum output level of 165 dB re 1 μPa @ 1m and a linearity of ± 8 dB in a frequency range from 44 Hz to 160 kHz. This is accomplished by an array of four electroacoustic transducers with associated frequency equalizer and power amplifier to provide the wide bandwidth and required power. A hydrophone monitors the acoustic output, a spectrum analyzer provides a real time analysis capability, and an instrumentation magnetic tape recorder records signals of interest.

This report describes how the signals are generated, transmitted, monitored, recorded, and analyzed.

SIGNAL GENERATION AND TRANSMISSION

The underwater acoustic signal generation and transmission system is comprised of a signal source, signal control and equalization circuitry, four power amplifiers with matching transformers, and four electroacoustic transducers forming an array to physically generate and project signals underwater. A block diagram representation of the system is shown in figure 1.

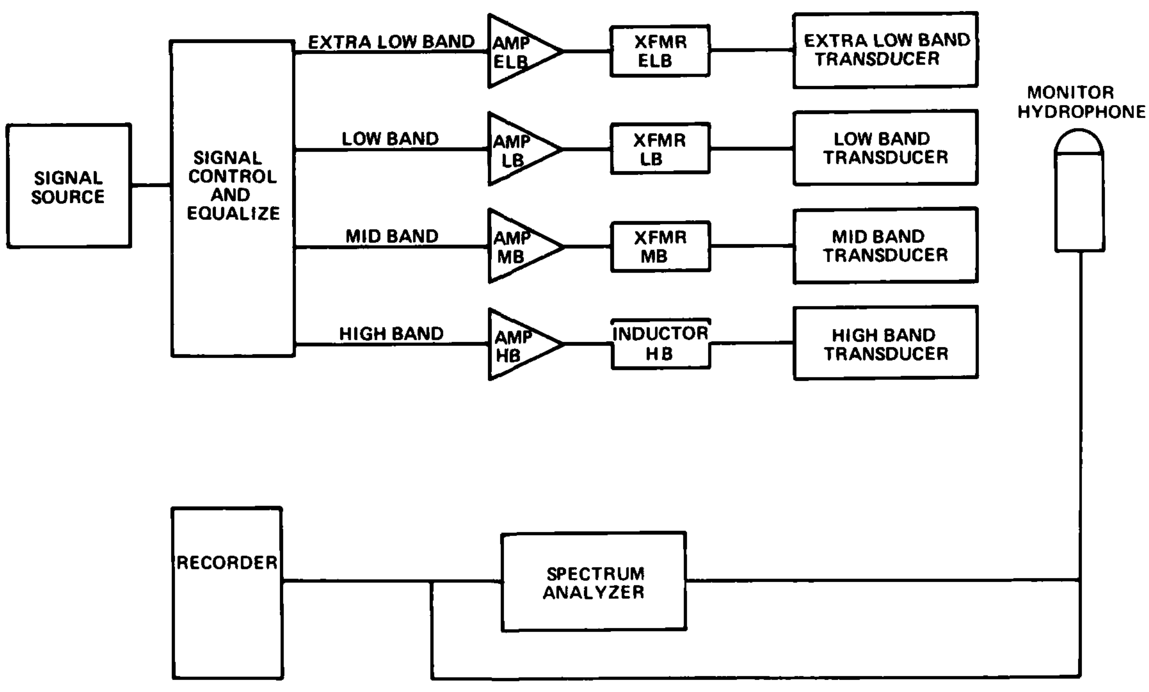


Figure 1. Wideband underwater acoustic transmission system.

In this system, the electrical signal source can be either a wideband magnetic tape recorder, a general purpose signal generator, or a random noise generator. However, any compatible signal source could be used. The random noise generator and signal generator are used primarily for system tuning and calibration, with the tape recorder providing the primary source of signals of interest.

The signal control and equalization circuitry as shown in figure 2 provides operator control of signal input and output switching, along with amplitude gain and amplitude equalization with frequency. The operator can select up to 14 input signals which are buffered, summed, and presented to the quiet switch.

The quiet switch is a gated amplifier that provides a gradual rise time (or decay for turnoff time) of the output signal amplitude when enabled. The "start" pushbutton enables the quiet switch, the event clock, and the event clock's digital readout. When enabled, the signal is gated through the quiet switch, and amplified by the operator-controlled variable gain amplifier, for distribution to the frequency equalizers, power amplifiers, and output transducers. The quiet switch output is disabled (after a random time delay of two to seven seconds) by the operator-controlled "stop" pushbutton.

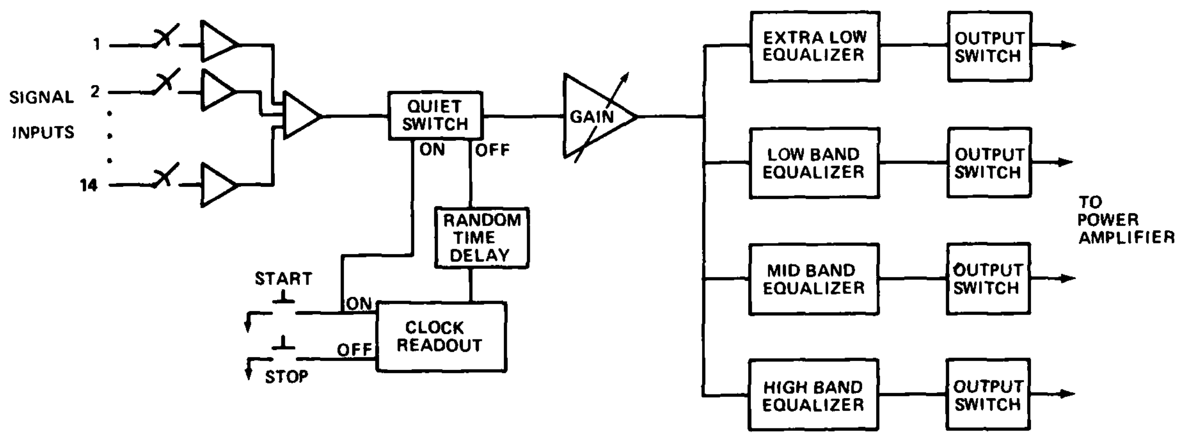


Figure 2. Signal control and equalization circuitry.

The frequency equalization circuits shape the signal so that the transducer's output in the water is a "good replica" of the signal originating from either the magnetic tape recorder or other signal sources. The equalizer circuits were designed specifically for the transducers they feed, and are unique as such. The frequency response of each equalizer is designed to be the inverse of its transducer's response so that a signal passing through both will emerge as an undistorted replica of the original signal.

Each of the equalizers has input and output variable gain amplifiers with cascaded operational amplifier filters, as shown in figure 3. The frequency response of the filters is adjustable by either reactive component replacement and/or potentiometer gain adjustment. Each of the equalizers was fine tuned to provide the best signal replication in the water. The equalized signals are then passed to the power amplifiers, transformers, and finally the output transducers.

The four power amplifiers receive the equalized signals and amplify these signals for transmission by the transducers. The power amplifiers' output impedances are matched to the transducers' input impedances with inductors or impedance matching transformers so maximum power transfer will occur.

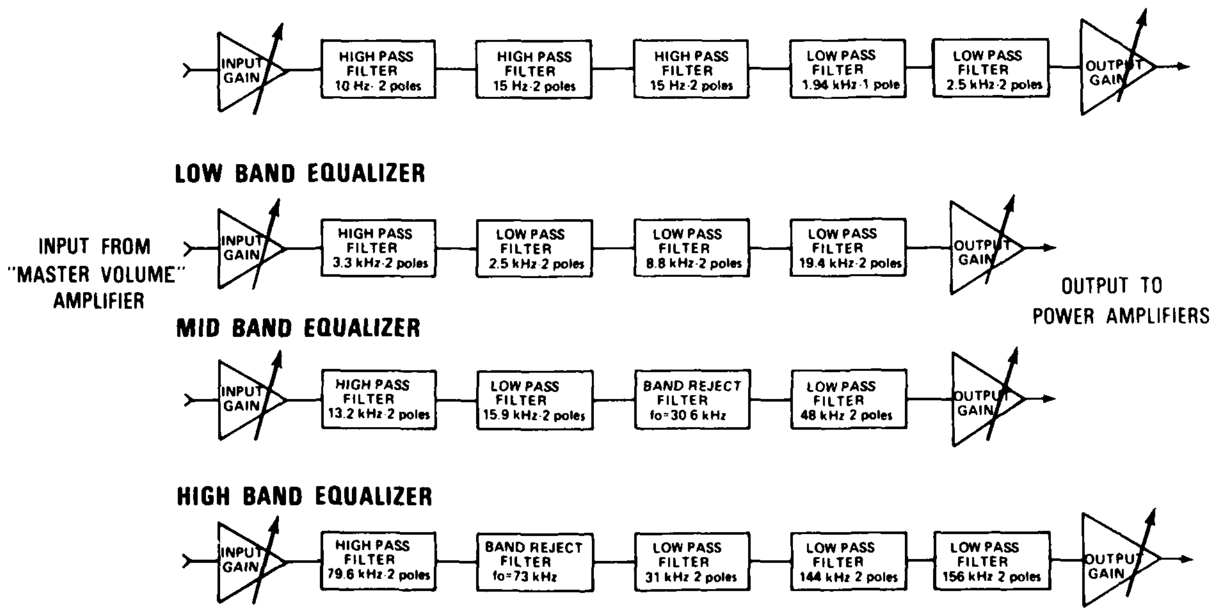


Figure 3. Frequency equalizers.

The four transducers (projectors) with contiguous operating frequency ranges and similar source levels were formed into a transmitting array in order to provide a constant power spectral density (i.e., a flat transmitted power frequency response) from 44 Hz to 160 kHz. The transducers receive the signals that have been shaped by the equalizers and amplified by the power amplifiers. All four transducers were designed and/or manufactured by the Underwater Sound Reference Division of the Naval Research Laboratory (USRD-NRL) in Orlando, Florida. The transducers are mounted coplanar in an array, as shown in figure 4, to approximate an omnidirectional wideband point source. The array was mounted on a vertical sled for insertion and removal from the water with a manual winch and pier davit.

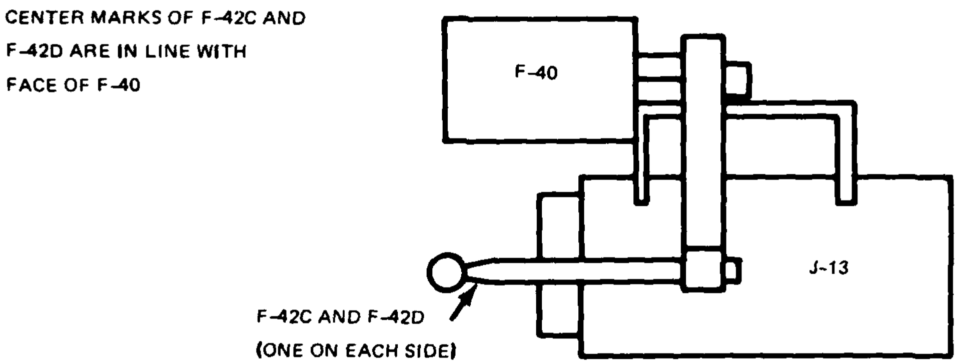


Figure 4. Underwater transducer array.

The largest projector in the array is a USRD-NRL model J-13 moving coil electro-acoustic transducer that covers the extra low frequency band of 44 Hz to 2 kHz. The low frequency band of 2 kHz to 20 kHz is covered with a USRD-NRL model F-40 lead zirconate titanate (LZT) transducer. A USRD-NRL model F-42B LZT transducer is used to cover the midband from 20 kHz to 60 kHz. The high frequency band from 60 kHz to 160 kHz was covered by a USRD-NRL model F-42D transducer. The transducer power outputs were balanced across the band from 44 Hz to 160 kHz by equalizer and/or power amplifier adjustments while projecting broadband (500 kHz) white noise, as shown in figure 5.

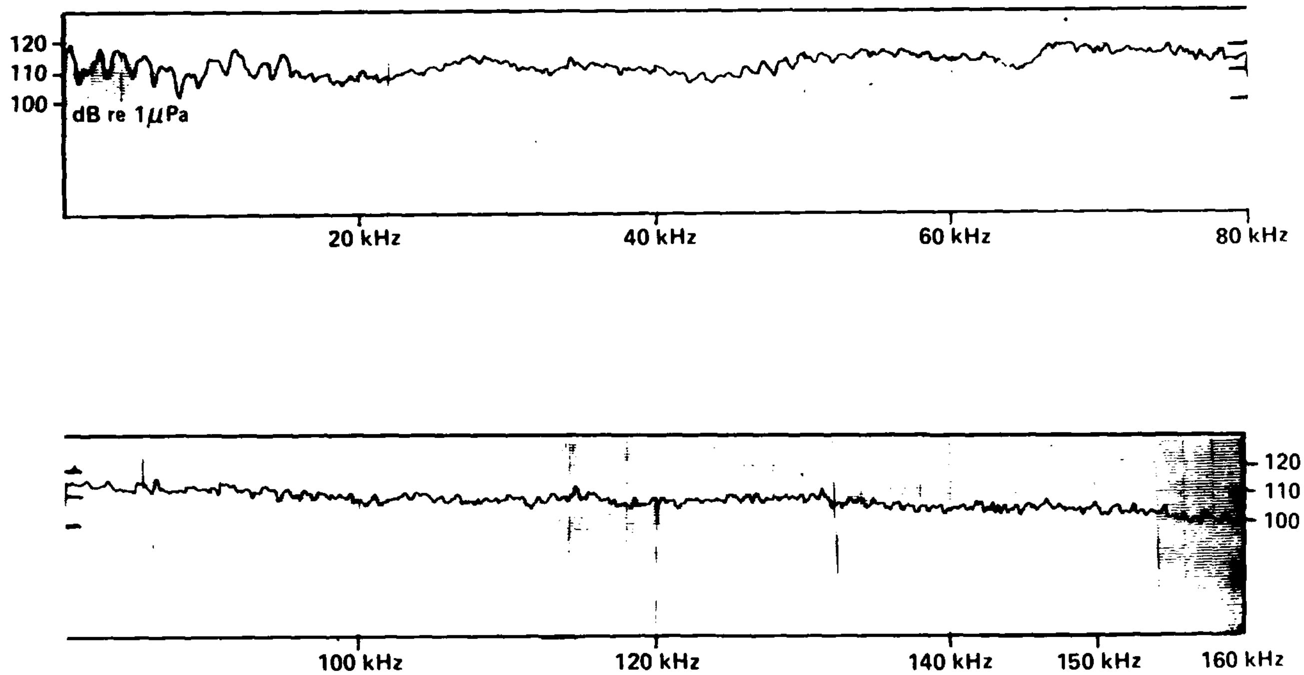


Figure 5. Transducer equalized power spectrum.

RECEIVING AND ANALYSIS SYSTEM

The receiving system consists of a broadband hydrophone and a high gain amplifier. The hydrophone, a Bruel & Kjaer model 8103 LST transducer, is omnidirectional with a flat (± 2 dB) frequency response from 1 Hz to 120 kHz and a useful (-10 dB) frequency response to 200 kHz. The hydrophone receiving sensitivity is -211 dB re 1V/μPa. This value is flat (± 2 dB) in the horizontal plane below 200 kHz and in the vertical plane below 100 kHz. The hydrophone is pole mounted 1 metre from the radiating face of the array to constantly monitor the array output.

The relatively low voltage signal from the monitor hydrophone is amplified by 1000 with a Bruel & Kjaer model 2635 charge amplifier. This high level signal is then distributed to a Kudelski audio amplifier/loudspeaker for aural monitoring and to the spectrum analyzer.

The spectrum analyzer is a Spectral Dynamics model 330 time compression analyzer with a Spectral Dynamics model 332 translator, permitting real-time analysis of any 20-kHz band up to 150-kHz band center frequency. Signal spectrum analysis can be in real time or ensemble averages with linear or exponential weighting. Since the hydrophone receiving sensitivity and amplifier gain are known, the signal measurements can be referenced to absolute sound pressure levels in the water.

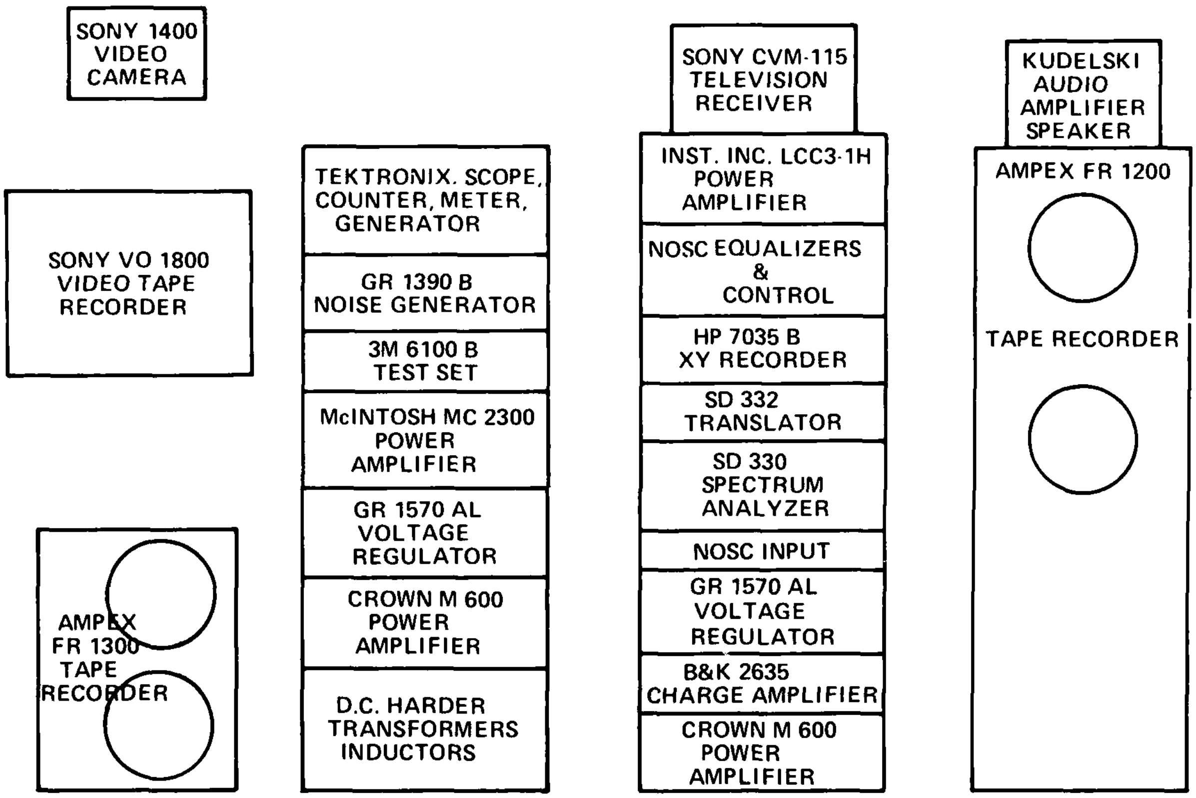
The spectrum analyzer output is recorded on a Hewlett Packard model 7035 hard-copy X–Y recorder with either linear or logarithmic amplitude display.

Acoustic events can be recorded on the Ampex model FR–1200, 14-channel wide-band instrumentation magnetic tape recorder. In the direct recording mode with Ampex 756 magnetic recording tape, the model FR–1200 provides a bandwidth from 150 Hz to 150 kHz (± 3 dB) with a 32-dB dynamic range at 30 ips. A wider signal dynamic range can be accommodated easily by adjusting the input signal gain in known increments (e.g., 10 dB) and recording the same signal but with the different gain levels. Ancillary information such as time codes, event counter, voice annotation etc. can be recorded easily for future reference.

SUMMARY

A unique underwater acoustic facility was designed and assembled to reproduce and analyze wideband underwater sounds. This system has the capability to project underwater sounds from 44 Hz to 160 kHz with an output level of 165 dB re 1 μPa @ 1m and a linearity of ± 8 dB. The analyzing and recording equipment used assisted in the development of the sound generating system and made it possible to analyze other broadband signals of interest.

APPENDIX A: EQUIPMENT BLOCK DIAGRAM



APPENDIX B: EQUIPMENT

Tape Recorder	Ampex FR 1200 S/N 1P2588	Ampex Corp., Redwood City, CA
Tape Recorder	Ampex FR 1300 S/N 1220404	Ampex Corp., Redwood City, CA
Spectrum Analyzer	Spectral Dynamics 330 S/N 143	Spectral Dynamics, San Diego, CA
Spectrum Translator	Spectral Dynamics 332 S/N 315	Spectral Dynamics, San Diego, CA
Random Noise Generator	Gen Rad 139B S/N 10350	General Radio, Concord, MA
Oscilloscope	Tektronix SC 502 S/N B023970	Tektronix, Beaverton, OR
Universal Counter	Tektronix DC 503 S/N B167818	Tektronix, Beaverton, OR
Function Generator	Tektronix FG 501 S/N B128916	Tektronix, Beaverton, OR
Digital Multimeter	Tektronix DM 502 S/N B029642	Tektronix, Beaverton, OR
Hydrophone	B & K 8103 S/N 680923	Bruel & Kjaer, Denmark
Hydrophone Amplifier	B & K 2635 S/N 699667	Bruel & Kjaer, Denmark
Test Set	3M 6100B S/N 00155	3M, Camarillo, CA
X-Y Recorder	H.P. 7035 S/N 1447A0741	Hewlett Packard, Palo Alto, CA
Audio Amplifier & Loudspeaker	Kudelski S/N 1634	Kudelski, Paudex, Switzerland
Voltage Regulator 1	GR 1570 AL S/N 3907	General Radio, Concord, MA
Voltage Regulator 2	GR 1570 AL S/N 4439	General Radio, Concord, MA

Extra Low Band 44 Hz - 2 kHz

Amplifier	Crown M 600 S/N 407	Crown Int., Elkhart, Ind.
Transformer	D.C. Harder P/N 98209	D.C. Harder Co., San Diego, CA
Transducer*	USN J-13 S/N 20	NRL-Underwater Sound Reference Div., Orlando, FL
Equalizer†	USN-Experimental	Naval Ocean Systems Center, Kailua, HI

Low Band 2 kHz - 20 kHz

Amplifier	McIntosh MC2300 S/N 1Y548	McIntosh Lab., Binghamton, NY
Transformer	D.C. Harder P/N 98210	D.C. Harder Co., San Diego, CA
Transducer*	USN F-40 S/N 38	NRL-Underwater Sound Reference Div., Orlando, FL
Equalizer†	USN-Experimental	Naval Ocean Systems Center, Kailua, HI

MidBand 20 kHz - 60 kHz

Amplifier	Crown M600 S/N 385	Crown Int., Elkhard, Ind.
Transformer	D.C. Harder P/N 98222	D.C. Harder Co., San Diego, CA
Inductor	D.C. Harder P/N 98203	
Transducer*	USN F-42B S/N 4	NRL-Underwater Sound Reference Div., Orlando, FL
Equalizer†	USN-Experimental	Naval Ocean Systems Center, Kailua, HI

High Band 60 kHz - 160 kHz

Amplifier	Inst. Inc. LCC3-1A S/N 001	Instruments Inc., San Diego, CA
Inductor	D.C. Harder P/N 98202	D.C. Harder Co., San Diego, CA
Transducer*	USN F-42D S/N 6	NRL-Underwater Sound Reference Div., Orlando, FL
Equalizer†	USN-Experimental	Naval Ocean Systems Center, Kailua, HI

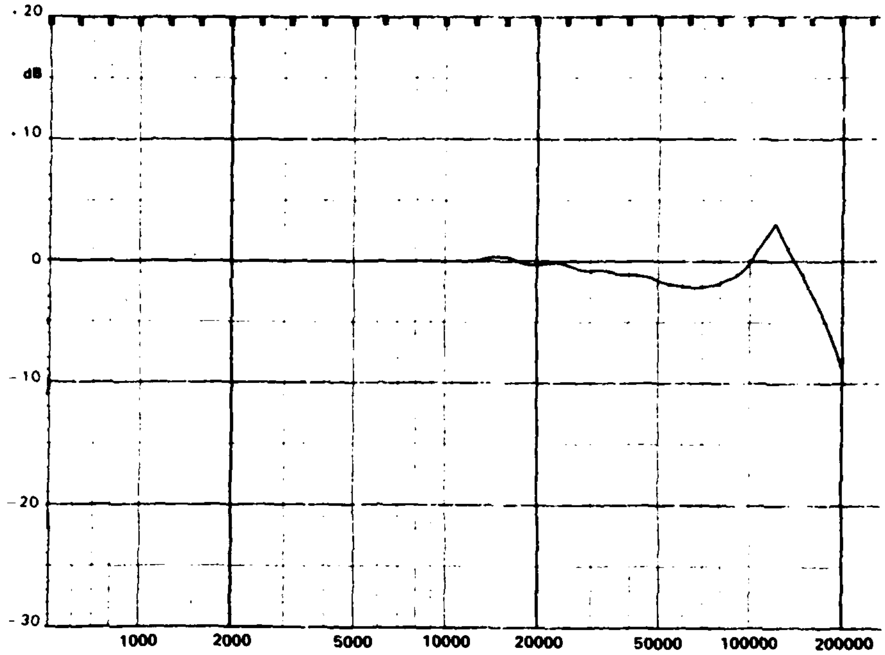
* See Appendix A for transducer calibration information.

† Equalizers for all frequency bands are individually manufactured by Naval Ocean Systems Center, Kailua, HI.

Video Tape Recorder	Sony VO-1800 S/N 13971	Sony Corp., Tokyo, Japan
Video Camera	Sony AVC 1400 S/N 23762	Sony Corp., Tokyo, Japan
Television Receiver	Sony CVM-115 10672	Sony Corp., Tokyo, Japan
Array Winch	Thern 402	Thern Inc., Winona, Minn.

APPENDIX C: HYDROPHONE AND UNDERWATER PROJECTOR CALIBRATION DATA

These calibration data were taken at NOSC's Evaluation Center, San Diego, CA. The Bruel & Kjaer 8103 hydrophone data were supplied by the manufacturer.



Calibration Chart for Hydrophone Type 8103

Serial No. 680923

Brüel & Kjær
Nærum Denmark

Reference Sensitivity at 250 Hz* at 23 C
including 6 m integral cable

Cable Capacitance 95 pF m typical

Open Circuit Sensitivity

Voltage Sensitivity

-210,7 dB re 1 V μPa**

-90,7 dB re 1 V per Pa or 29,2 μV per Pa

110,7 dB re 1 V per μbar**

Charge Sensitivity 103 10^{-3} pC per Pa

Capacitance (including 6 m cable) 3540 pF

Frequency Response
Individual Free Field Frequency Response Curve attached

Date 3 11 77 Signature J D

Summarized Specifications
Usable Frequency Range 0 1 Hz to 200 kHz (10 dB)

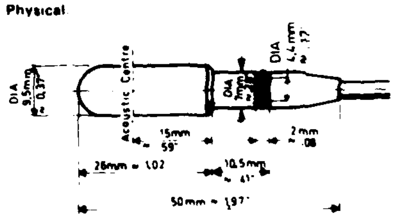
Linear Frequency Range
0 1 Hz to 20 kHz + 1 dB
0 1 Hz to 140 kHz + 2 dB

Horizontal Directivity 200 kHz (XY plane)
typical + 2 dB

Vertical Directivity 100 kHz (XZ plane)
typical + 4 dB

BC 0094

Physical



Leakage Resistance
7 1 10 MΩ at 23 C

Operating Temperature Range
40°C to + 120°C
40°F to + 248°F

Change of Sensitivity with Temperature
Charge < 0 03 dB °C
Voltage < 0 03 dB °C

Change of Sensitivity with Static Pressure
3 • 10 -7 dB Pa (0 03 dB ato)

Temperature Transient Sensitivity < 50 Pa °C
(ANSI S 2 11 1969), measured with B & K Charge Preamplifier Type 2626 LLF 3 Hz

Allowable Total Radiation Dose $5 \cdot 10^{7}$ Rad

Acceleration Sensitivity < 130 dB re 1 μPa g

Maximum Operating Static Pressure
40 ato

Cable
Double shielded low noise low capacitance
Integral cable 6 m with miniature plug

Weight (incl cable) 170 g
* Traceable to NBS
** 1 Pascal = 1 N/m² = 10 μbar

Figure C-1. Calibration chart for Bruel & Kjaer 8103 hydrophone.

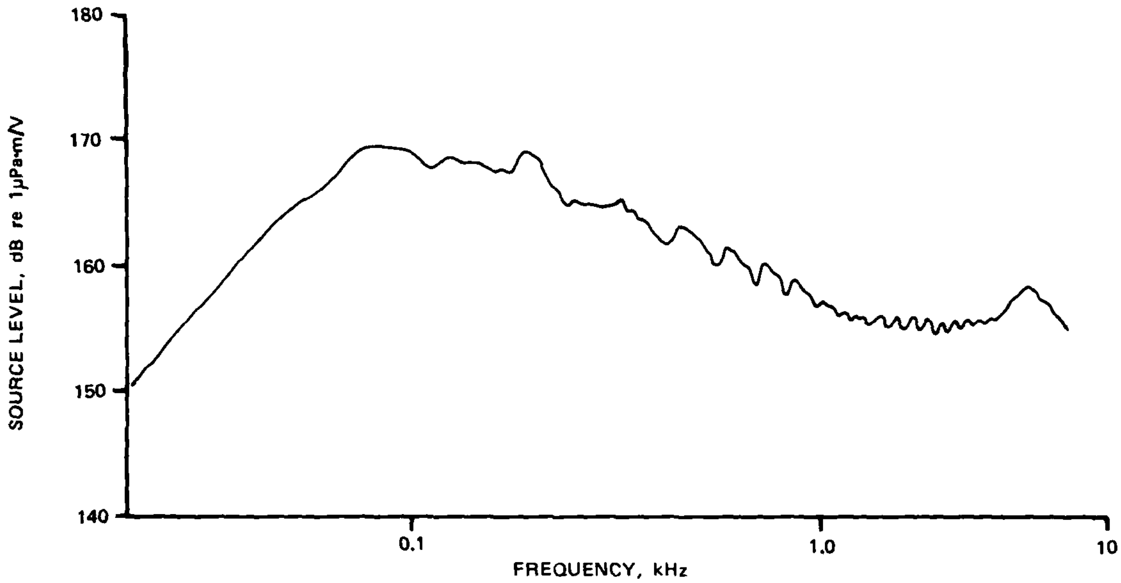


Figure C-2. J-13 transmitting voltage response.

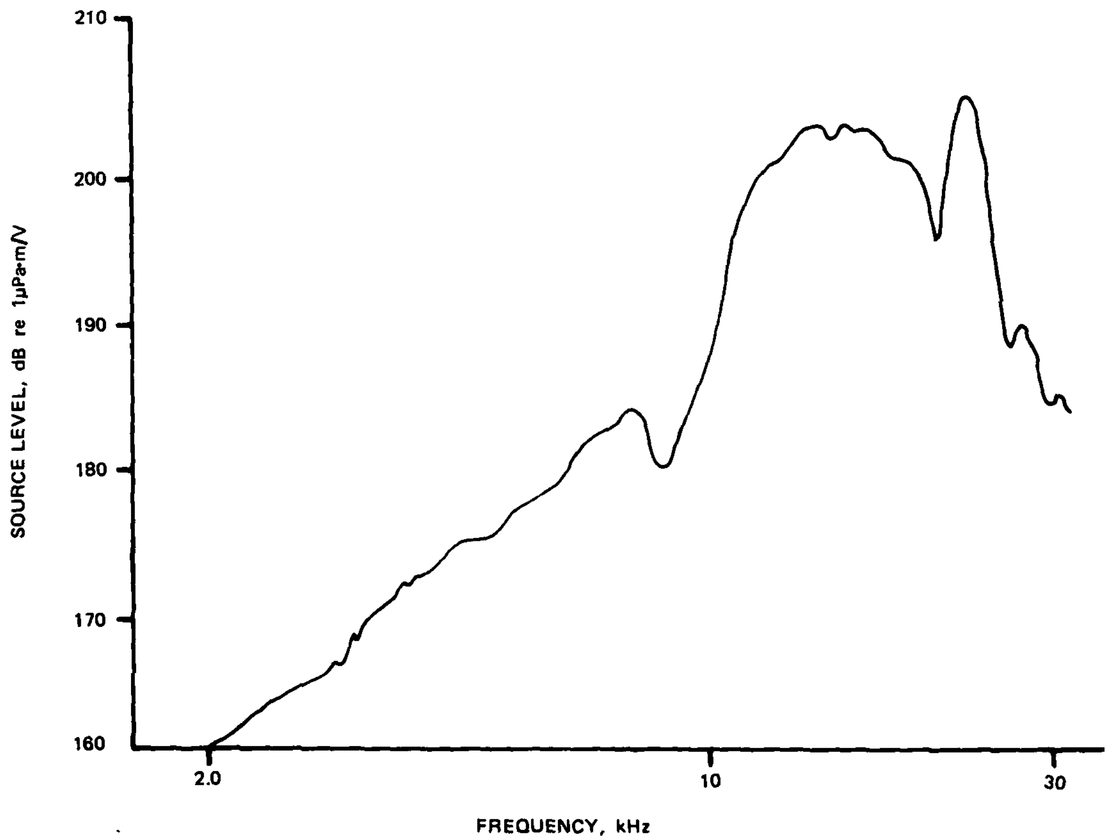


Figure C-3. F-40 transmitting voltage response.

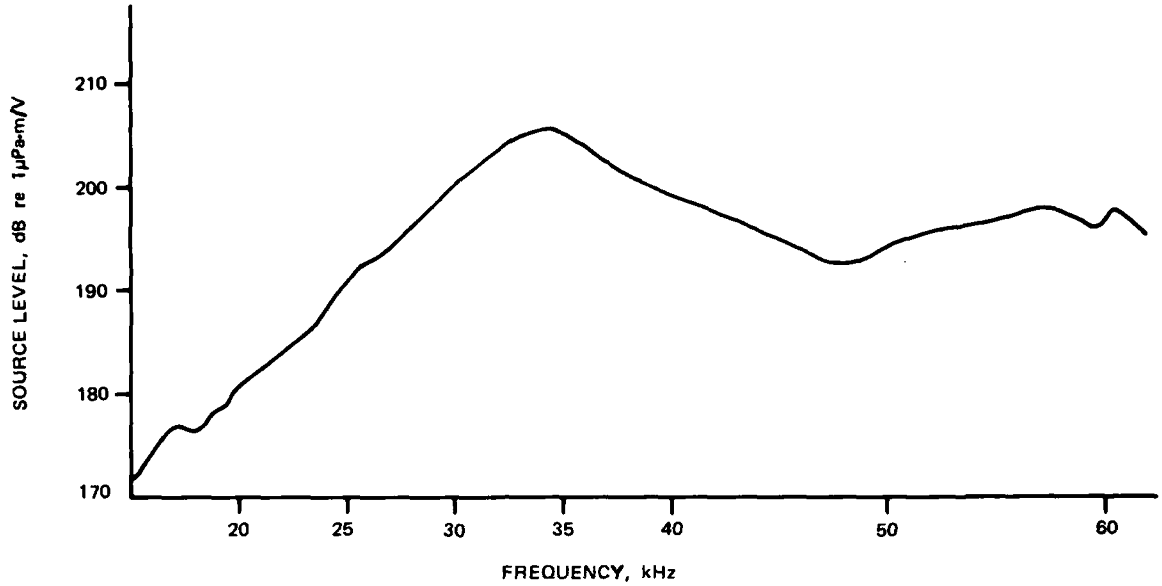


Figure C-4. F42B transmitting voltage response.

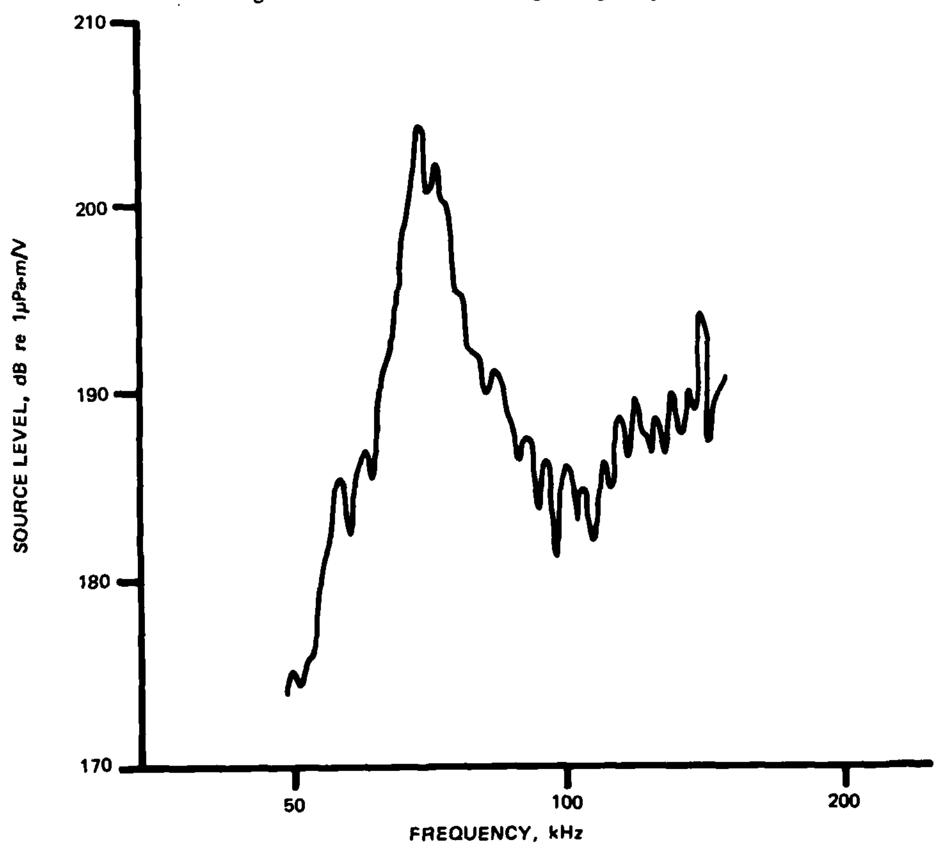


Figure C-5. F42D transmitting voltage response.